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A global wave power resource and its seasonal, interannual and long-term variability

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HIGHLIGHTS

- A new global wave energy assessment is presented, covering the longest time-span to date.
- Temporal variability globally is studied at: monthly, seasonal, interannual and long-term scales.
- We study the link with the most relevant climate indices globally.
- Decadal long-term changes are identified, they could be partly explained by natural variability.
- The global wave power is estimated at 32 GW h/yr, or 16 GW h/yr considering the direction of the energy.

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ABSTRACT

Assessments of global wave power have been receiving increasing attention currently; however, a characterization of the global resources that holistically consider the different temporal scales that influence wave climate (monthly and seasonal, interannual and long-term) is still lacking. Moreover, the debate around the global figure of available resource is still widely open. This study provides a new global wave power assessment using a dataset that covers the period from 1948 to 2008, which was corrected using altimetry data and validated with buoys in terms of wave power. This study characterizes the mean wave power globally as well as its monthly and seasonal variability. Furthermore, it provides a link with the most relevant climate indices globally. The effect of the interannual variability is especially noteworthy for the Northern Hemisphere, where the seasonality is strongest. Additionally, we detect decadal long-term changes and determine that natural variability could explain a few of the differences found between decades. Lastly, we provide an assessment of the global theoretical wave power that covers the last six decades, compare approaches and estimates, and discuss factors of discrepancy. The global offshore wave power is estimated at 32,000 TW h/yr, which is reduced to 16,000 TW h/yr when considering the direction of the energy. The historical average change is 580 TW h/decade. Our results indicate that the global natural variability could be a more relevant factor in the lifetime of wave farms than the historical long-term changes in wave energy.

1. Introduction

Within renewable energies, wave energy is experiencing increasing interest and development. It is expected to become economically competitive through the development of new designs and technical improvements [1–4]. However, resource variability can play an important role in cost-efficiency, with research indicating that wave energy farms' financial returns can be intimately linked with climate variability [5]. Furthermore, wave variability is also a decisive factor for selecting adequate locations from a technical standpoint [6]. Thus, in its pre-commercial phase, significant research is being conducted on the evaluation and characterization of the wave energy potential.

There are few studies that describe the mean global wave energy resources [7–13] (see Table 1). In terms of variability, Cornett [7] provides the indices of monthly and seasonal variations. Barstow et al. [8] addresses the variability of the resource for a 10-yr period while Mackay [9] derives the standard deviations from a 6-yr dataset. Both studies are based on numerical wave data

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Table 1
Comparison of the primary studies on global wave power that use reanalysis data. The columns include: model used, spatio-temporal resolution, period of analysis, validation work and type of study. The types of studies are classified as follows: PR – Potential Resource assessment; and TWP – Theoretical Wave Power assessment, with -O denoting the Omnidirectional approach and -D denoting the Directional approach.

Study	Model	Resolution		Period of analysis (yr)	Errors and validation	Type of study
		Time (h)	Space (°)			
Cornett [7]	N-WW3	3	1.25 × 1.0	10	Tolman [33]	PR
Mork et al. [11]	ECMWF-WAM	6	0.5 × 0.5	10	Barstow et al. [8]	PR TWP-O
Gunn and Stock-Williams [12]	N-WW3	3	0.5 × 0.5	6	Barstow et al. [8]	PR TWP-D
Arinaga and Cheung [10]	WW3	n/a	1.25 × 1.0	10	Arinaga and Cheung [10]	PR
Current study	WW3	1	1.5 × 1.0	61	Reguero et al. [29]	PR TWP-O TWP-D

from 1996 onwards. Additionally, Arinaga and Cheung [10] describe the monthly variations for wind and swell contributions from a 10-yr reanalysis and present the monthly variations on a global scale. However, wave climate varies over longer time scales than months: from year to year (i.e., interannual variability) or even longer. This range of variability has not yet been appraised for the wave energy resources.

None of the previous studies cover the interannual variability or long-term changes, which is primarily due to the short time spans that they cover. Studies on the available global resource rely on satellite altimeter or wave reanalysis data [7–14]. Most of these studies focus on the mean wave energy potential; however, its temporal variation has received lesser attention. As noted by several studies [15–17], the primary disadvantage of wave power, given the random nature of waves, is its large variability in different time scales, i.e., wave to wave, sea state, monthly, seasonal and inter-annual variations. The interannual variability is caused by large-scale climate characteristic patterns that affect wave climate (climatic variability). Researchers have studied wave climate variability at several temporal scales and discovered connections with different climate indices [e.g., 18–25]. The findings indicate that climate patterns, such as the North-Atlantic Oscillation or the Southern Annular Mode, influence the wave climate and, consequently, vary the available wave energy power. However, the periods of analysis of a few years are too short to capture the interannual variability given that the complete life cycle of the WEC farms will extend over various decades. On a regional scale, researchers are attempting to advance in the understanding of seasonal and decadal oscillations. For example, Ching-Piao et al. [26] indicate the relationship between the El-Niño phenomenon and the wave energy for the northeast coast of Taiwan.

For a longer time frame, Harrison and Wallace [27] note that the changes in the climatic conditions could also influence the resources in the longer term. However, the long-term trends in wave power have not yet been specifically determined primarily because long-time span wave data are scarce. Nevertheless, several studies point to the decadal changes in wave height from both satellite observations and numerical data (e.g., [19,28]).

Furthermore, there is a vivid debate on the actual figures of available global resources, with 2 TW h often being cited as the best estimate. Much of the uncertainty around this global potential comes from the data itself as well as the methods. For instance, Mork et al. [11] obtain estimates of the available theoretical wave power along the worldwide coastline on a regional basis and from reanalysis data. Additionally, Gunn and Stock-Williams [12] factor in the direction of the wave energy flux and thus obtain lower estimates. This study, using a long time span dataset, provides new estimates, compares approaches and quantifies long-term changes and variability of these global figures.

This study provides new contributions to the understanding of global wave energy and its variability in different fronts. First, it presents a new global assessment of wave power and its variability using a calibrated and validated 61-yr wave reanalysis. Additionally, we consider the temporal variability of the resources in months, seasons, years and decades. Next, we study the nexus between the wave power and the natural climatic variability globally. Lastly, the study provides a global coastline wave energy potential resource, compares available approaches, explains its range of variation and provides a quantification of past long-term changes over 6 decades. We determine that factoring in the wave direction is key for estimating the global resources.

2. Methodology and data

2.1. Methodology

This study takes advantage of different data sources and approaches to describe the available wave power statistics. The general methodology requires several steps (Fig. 1): (i) generation of a long time span wave reanalysis database, (ii) calibration with altimeter data, (iii) validation with buoy data, and (iv) assessment of the wave energy resource in deep water.

Thus far, only Mackay [9] provides an assessment based on satellite data. The rest of the available studies rely on hindcast data. Table 1 provides a list of assessments with global coverage

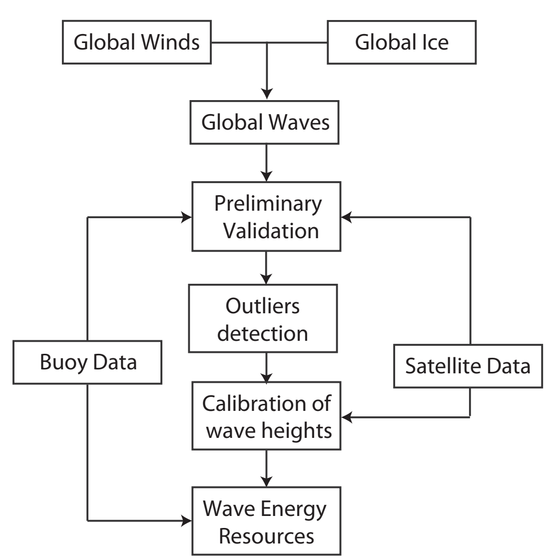

Fig. 1. Methodology to evaluate the offshore wave energy resource potential.